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How circular design can contribute to social sustainability and legacy of the FIFA World Cup Qatar 2022™? The case of innovative shipping container stadium

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ABSTRACT

The circular economy proposes a paradigm shift from the 'take-make-waste' type of economic system and aims to foster innovation, resource efficiency, and waste prevention. Mega sporting events can be considered great opportunities to promote sustainable cities and communities and leave a lasting positive legacy after the post-game stage. Qatar will organize the upcoming FIFA World Cup in 2022 and Ras Abu Aboud (RAA) is designed as a fully reusable and modular shipping container stadium, which will be dismantled, relocated, and reused after the tournament. This study aims to present the first comprehensive analysis on the social sustainability and legacy aspects of a circular and sharing economy application for the FIFA World Cup organization. The research analyzes the entire life cycle phases of the RAA stadium including the raw material production, construction, operations, and end-of-life. The Ecoinvent v.3.7.1 is used to quantify the midpoint environmental and endpoint human health impacts. For its operation phase assessment, two operation scenarios are comparatively analyzed: one-year temporary operation (Scenario 1) and 50 years of permanent operation (Scenario 2). Later, a simulation-based sensitivity analysis is conducted. Finally, we discussed how circular and modular design thinking can bring long-lasting legacy post-event, through reuse and recycling from a socio-economic perspective. An important finding shows that circular design under Scenario 1 can save up to 60% of human health impacts and significantly reduce the material footprint and dependence on imported construction materials. This research will enhance future awareness for sustainability benefits of circular and sharing economy application adopted by mega sporting events concerning the United Nations 2030 Agenda for Sustainable Development and FIFA's post-game legacy and sustainability strategies.

1. Introduction

1.1. Overview

The 2022 FIFA World Cup™, mega-event setting milestones in Qatar's figurative records has laid unique opportunities in delivering legacy and sustainable prosperity to the state concerning the Qatar National Vision 2030. It is frequently argued that the prime motive of a country to organize a "mega-sporting event" is the economic benefits of the event on the local market (Preuss, 2006). FIFA World Cup events are not only attracting global interest and media attention for the host countries but are also a leading cause behind shaping tourism and

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introducing new touristic destinations, promoting investments and business alliances, and creating a positive socio-economic impact (Ntloko and Swart, 2008). Sporting events also utilize a substantial amount of resources leaving prolonged impacts on the host state and neighbors. Large-scale construction projects like stadiums are responsible for massive carbon emissions globally. The consequences of carbon emissions have led Qatar to commit in delivering a carbon-neutral 2022 FIFA World Cup which in return would leave a sustainable legacy for the country (FIFA, 2019a, 2019b). The commitment lies not only in cutting down the Scope 1 and Scope 2 related emissions, but also the indirect Scope 3 emissions (FIFA, 2019a, 2019b). Monitoring the emission statistics require advanced tools, and some researchers suggest blockchain technology for this purpose, thus supporting circularity (see Upadhyay et al., 2021). Data blocks could be used to support circular economy initiatives in the built environment and urban spaces (Shojaei et al., 2021). Academics, governments, and businesses around the world are actively researching potential methods to reduce the negative environmental impacts in construction by using green construction strategies (Kucukvar et al., 2014; Kucukvar et al., 2016). However, sustainable construction goes far beyond environmental and economic concerns and has other tangible outcomes namely in the social sphere.

Stadium construction is gaining more and more attention, as world cup events tend to shift efforts towards achieving carbon neutrality and sustainability (Safir, 1997; Miller, 2002; Jones, 2002; Alegi, 2008; Kellison et al., 2015; Al-Hamrani et al., 2021). Construction is considered one of the major sectors that hold the impact on sustainability: economically, socially, and environmentally (Medineckiene et al., 2010; Onat et al., 2014b; Stasiak-Betlejewska and Potkány, 2015; Dong and Ng, 2016). Recent statistics reveal that construction contributes to 50% of climate change, 23% of air pollution, and 50% of landfill wastes (Huang et al., 2018). According to Urge-Vorsatz and Novikova (2008), the building sector contributes nearly 33% to the global carbon dioxide (CO_2) emissions, making construction the second greatest carbon-emitting sector followed by the manufacturing sector in both the developed and developing countries. Consequently, this suggests the need for eco-friendly strategies to be implemented in maintaining societal health and welfare, providing opportunities for the current and future generations to flourish (Al-Hamrani et al., 2021). The standard model of production, which is based on the three aspects of taking, make and dispose of is not effective anymore (McDowall et al., 2017). In other words, a linear way of resource consumption where more production requires more resources and produces more waste should be replaced with a circular method where resources are initially obtained from the environment but later on, waste produced becomes the resource itself (Bonviu, 2014). Circular economy contribute to an innovative circular design concept is highly adopted and considered at a global level, where both the private sector and governments are focusing on resource-related sustainable innovations (Preston, 2012; Corona et al., 2017; Onat et al. 2014a; Finch et al., 2021), where we will focus on at this paper.

1.2. Research objectives and motivation

The proposed study is set out to understand and quantify the social impacts of reusable stadium construction utilizing a social life cycle assessment approach. The research relies on data collected for the reusable container stadium design construction, taking the case of Qatar's Ras Abu Aboud (RAA) stadium. Human health damage point was taken into account as the target point of protection. This data is then processed using several scenarios to draw a comparison between different scenarios and illustrate the social benefits induced by the innovative construction of shipping container stadiums. This research thus aims to:

a) *Conduct* a “Social life cycle impact assessment (S-LCIA)” using the End-point impact method to understand the human health-related damages linked with the RAA stadium construction case study.
b) *Identify* the significant contributors across each mid-point impact category namely; climate change, human toxicity, ionizing radiation, ozone depletion, particulate matter formation, and photochemical oxidant formation and, the potential impact categories that inflict damage to human health across each phase of the life cycle, with a future scenario analysis for the operation phase of the stadium.
c) *Build* sensitivity analysis to distinguish the most sensitive impact categories using volumetric changes to the most significant contributors across each life cycle phase.
d) *Develop* the end-of-life management of RAA stadium as a case study by applying a cradle-to-cradle life cycle management approach.
e) *Discuss* the legacy and socioeconomic benefits of circularity and modular design in relation to the United Nations Sustainable Development Goals and FIFA's post-game sustainability strategies.

2. Literature review

2.1. A tale of sustainability in mega-events

Over the last decade, global climate change and environmental concerns gained an increased interest particularly in terms of their impact on host cities, residents, and audiences. Consequently, sustainable approaches associated with mega-events are starting to get more recognition and are primarily presented in the bidding process (Holmes et al., 2015). The first recognized FIFA World Cup to apply sustainable greening agenda was Germany in 2006, where the “Green Goal” initiative was created to cut down the environmental impacts related to the World Cup organization (Death, 2011). The world cup focused mainly on four key areas namely; energy, sustainable transportation, water, and waste management. According to reports, Germany in 2006 achieved carbon-neutrality, however, they did not take into account the international travel carbon emissions for spectators and other related parties in their calculations that form a major part of total carbon emissions (FIFA, 2006). After the German World Cup set the new standard, it was difficult for a developing country burdened by penury and social inequality like Southern Africa to surpass. A different priority was set in the South African 2010 World Cup which focused on social and economic development rather than environmental mitigation. As a result, the tournament showed good performance although it never reached the anticipated potential. The most significant impacts of the tournament included the development of public transport systems and infrastructure, job creation, and a boost in tourism. However, the event lacked organization and it raised questions due to spending public money on expensive “white elephant” stadiums, when many of South Africa's population were in desperate need of adequate and safe housing (Death, 2011).

The 2014 World Cup in Brazil had similar impacts as South Africa. Again, an emerging country seized the opportunity to host the tournament in hopes of leaving a positive impact on the national economy by creating sustainable job opportunities, improving the hotel and tourist industry, and accomplishing projects in construction by upgrading rail and road transport infrastructures. Instead, there was a slowdown in the national economy and criticism of human rights violations. In angry protests and financial concerns, environmental sustainability was mostly neglected (Paula, 2014). The recent 2018 Russian World Cup™ had quite a modest amount of research addressing the sustainability results and various issues of the tournament (Ermolaeva and Lind, 2020). According to the official FIFA report, the residents of host cities have observed a positive impact the tournament left on urban infrastructure development and raised awareness on reuse, climate crisis, and biological heterogeneity through the held campaigns (FIFA, 2019a, 2019b). The event allowed Russia to revive cities such as Moscow from an urban slant of growth and participate in green building projects both domestically and in other countries as a part of carbon footprint offsetting strategies (Talavera et al., 2019; Ermolaeva and Lind, 2020). As Qatar is set to host the 2022 World Cup tournament, key sustainability concerns associated with the "triple bottom line" concept must be given equal priority to ensure that the event leaves a positive legacy on the host country and its residents. (Supreme Committee for Delivery and Legacy, 2020).

2.2. Social life cycle assessment in sustainable construction

Social Life Cycle Assessment (S-LCA) aims to evaluate the potential impacts of social and socio-economic aspects for all phases of any product/process life-cycle, including but not limited to extraction, processing, manufacturing, assembling, selling, reusing, and recycling (Benoît et al., 2010). Several studies have used the Environmental LCA (*E*-LCA), but there is a handful of studies found in the literature on S-LCA conducted especially in the construction sector, although building projects are constructed to enhance social aspects related to improving the quality of life (Egilmez et al. 2014; Sala et al., 2015; Dunmade et al., 2018). Dong and Ng (2015) aimed to develop a "Social-impact Model of Construction (SMoC)" for infrastructure development programs in Hong Kong. The study revealed that the use of "precast concrete components" did harm stable earnings and the local job market, as the precast concrete was usually imported from neighboring states. While, Navarro et al. (2018) studied the social impact of a concrete bridge deck in Spain. To conduct this study, social impacts of alternative designs were measured paying attention to the impacts resulting from the construction and maintenance phases under conditions of uncertainty. Hosseinijou et al. (2014) stated that the selection of materials during the building construction phase should not only take into consideration the functionality but also should consider the "triple bottom line" impacts. Assessment of material's social impacts should address the complete life cycle. Corona et al. (2017) in their research aimed to add suggestions for improvements on the characterization model built by previous methodological developments. The most identified social risk was related to; gender inequality and corruption that were both confirmed by site-specific assessment, while injuries and immigration aspects were not accounted for. While, Dunmade et al. (2018) evaluated the potential social impacts that the engineering project management process may have on stakeholder categories. Referring to "UNEP/SETAC guidelines" for S-LCA, an infant food production plant was taken as the case study. Results revealed that the social performance of project managers towards the community is better than towards the project team itself. The study by Bork et al. (2015) is somehow related to construction, conducted to assess the social life cycle of three furniture companies. According to the results, companies should consider the training of employees as a way to reduce accidents. As for green building designs, the study of Fan et al. (2018) analyzed the social needs of green building design using the LCA method. Different stakeholders were taken into consideration such as the real estate developers and community residents. Results proved that individuals are willing to pay to enjoy a better living environment, also, the local authorities are supportive of the development of green housing districts. A study on green concrete was done by Kono et al. (2018) to assess the socio-environmental factors. Hot spot analysis, as well as LCA, was also conducted. Results showed that the use of green concrete was environmentally beneficial but had negative social impacts. Essentially, the S-LCA method has been successfully implemented to analyze the social needs of various construction-related projects.

2.3. Circularity and green design in construction

Circular Economy (CE) in line with the construction sector can be described as a restorative design model that uses the circular flow of materials to guarantee practicability and value of assets at all times (Geissdoerfer et al., 2017). The principles of CE are quite simple, and start with the design phase of the products, considering the use of components that are biological and technical, and can be composed or refurbished and reused afterward. Other principles include the use of green energy sources, understanding the relationships between various elements so that comprehensive systems are developed. Most importantly, CE does not consider the impact on the environment alone but also takes into consideration other aspects including the socio-economic dimensions during the full lifetime of a system (Al-Hamrani et al., 2021).

Recent trends in construction industries and infrastructure development are moving towards the application of a CE in reducing possible burdens on the environment (Kucukvar and Tatari, 2012; Kutty et al., 2020b). At present, there are various green design alternatives applied in buildings such as intelligent facades, passive solar systems, vertical planting, energy-efficient designs, and the use of recycled materials, just to name a few (Pons-Valladares and Nikolic, 2020). In the case of the FIFA World Cup tournaments, FIFA has detailed the green building principles and certification requirements in their 'Technical Recommendation and Requirements' handout. According to FIFA (2011), the newly constructed stadiums must be eligible for the Leadership in Energy and Environmental Design (LEED) certification, incorporating sustainable and green building design measures that include: use of energy-efficient strategies for lighting and air-conditioning, a passive design that reduces heat and improves air circulation, use of non-toxic and recycled materials, all tailored towards reducing the total waste. Thus, with proper analysis, design, and operational strategies, the prospect of stadium construction can become a positive experience during the construction till the end-of-life stage.

Ever since the age-of-industry, the conventional 'take-make-waste linear economy model has been extensively applied in society, however, due to its limitations this production and consumption model is becoming incredibly unsustainable (Kutty and Abdella, 2020). Most recently, businesses and governments around the globe have started noticing the fact that resources are not infinite and are actively reaching planetary boundaries. The continuous exhaustion of natural resources into waste as a result of production activities contaminates our ecosystem (Nandi et al., 2021). In light of these challenges and the underlying limitations imposed by the 'linear economy model', the scientific and global policy communities are gradually attracted by the concept of a circular economy. Since the human-made environment is causing a carbon stock in cities, the use of recycled and bio-based building material generated from waste handle an essential role in climate change alleviation (Caldas et al., 2021).

2.4. State-of-the-art contribution

There is abundant literature that focuses on sustainability concerns in mega-events including studies on carbon footprint accounting for Beijing 2008 Olympics (Wu et al., 2011), environmental footprinting in 2003/2004 Football Association Cups (Collins et al., 2007), and studies on quantitative environmental impact assessments in FIFA World Cups (Collins et al., 2009; Pereira et al., 2017). Surprisingly, the socio-economic dimensions of sustainability were not considered in any of these studies, even though they hold vital significance compared to the environmental impacts and are all interrelated (Talavera et al., 2019).

Furthermore, while searching through the body of knowledge in the area of "life cycle sustainability assessment" in the construction sector, social indicators are not studied sufficiently. S-LCA has not widely been applied yet due to the subjectivity that arises when selecting the social indicators (Onat et al., 2017; Egilmez et al., 2013). CE applications for World Cup Stadiums in particular and the application of sustainability assessment, in general, is limited to green stadium designs. It is noteworthy that, there is a lack of concern when it comes to estimating the social impacts like human health under the circularity theme for mega-events when sustainability scientists and decision-makers raise voice on the increased impacts of emissions.

Lastly, there is a lack of studies that conduct a complete social life cycle sustainability assessment (considering all the phases – cradle to cradle approach). Thus, in the limelight of these gaps, this research aims to conduct the first of its kind S-LCA to calculate the mid-point environmental and associated end-point human health-related damages concerning the RAA stadium construction. Furthermore, we discussed the contribution of modular design, reuse, recycle, re-allocation and resource-sharing practices of some structural components to the United Nation Sustainable Development Goals and FIFA's post-game legacy and sustainability strategies.

3. Methods

Although the traditional LCA tool is used in evaluating the environmental impacts linked to all stages of a systems life cycle (Singh et al., 2011; Kucukvar et al., 2017; Park et al., 2015; Sen et al., 2020), the social impacts will mainly be addressed in this study. The entire social LCA process for the RAA stadium will be conducted as per the research flow chart shown in Fig. 1. Further details of each step will be presented in the following sub-sections.

3.1. Case study

RAA stadium is one of Qatar's FIFA 2022 WC stadiums that will host matches in the group stage and the round of 16 with a capacity of 40,000 spectators. According to the “Supreme Committee for Delivery and Legacy (SCDL)”, unlike other stadiums, the main structure of the RAA stadium was constructed from a total of 972 shipping containers, structural components made from steel, and removable seats. While, knowing that concrete worldwide accounts for huge CO_2 emissions (Marie and Quiasrawi, 2012), the followed strategy has induced lower usage of concrete materials, which reduced pollution and carbon footprint. On the other hand, this innovative design will allow the stadium to be entirely dismantled after the end of the WC event, setting a precedent in the history of the WC stadiums, and confirming Qatar's commitment to sustainability and carbon neutrality (Supreme Committee for Delivery and Legacy, 2020), as many parts of the stadium, including all its seats, shipping containers, and the roof will be repurposed in other sport and non-sport facilities to benefit the society.

3.2. Goal and scope definition

The study targets to conduct a cradle-to-cradle social LCA of RAA stadium based on the data provided by the World cup 2022 organizing committie using the ReCiPe method. The scope in this study includes four different phases illustrated in the system boundary shown in Fig. 2 which are (1) material production phase, (2) construction phase, (3) operation phase, and (4) end of life phase. The entire area of the stadium, which constitutes 80,531 m^2, will be used as the “functional unit” in this study. Fig. 2 shows the stages involved in the S-LCA assessment from a cradle-to-cradle perspective.

3.3. Life cycle inventory data

The physical materials and energy flows entering and leaving the system is captured through the “life cycle inventory analysis (LCIA)” (International Organization for Standardization, 2006a, 2006b). For this study, the LCI data presented in Table 1 represent site-specific data obtained from the SCDL at several stages of the RAA stadium's LC. The recycled amount column in Table 1 indicates material quantities that were avoided during the production phase, as recycled material was combined with the virgin material in the production process of some of the listed products. The Ecoinvent v3.7 database has been utilized to aggregate the quantified data into several impact categories, which will be identified in the following sub-section. The activity and the reference product names in Ecoinvent v3.7, which has been used to obtain the characterization factors for different impact categories, are also shown in Table 1. It is worth mentioning here that for each activity identified in Ecoinvent v3.7, the geographical location dataset under the RoW was chosen, which refers to the “Rest-of-World”.

3.4. Life cycle impact assessment

The “life cycle impact assessment (LCIA)” is the next step in which the impacts induced from the LCI data shown in Table 1 will be evaluated after assigning them to certain impact categories. For this purpose, in the Ecoinvent v3.7 database, the ReCiPe method has been implemented using the damage-oriented methodology (endpoint) to evaluate the social (SLCIA) of the RAA stadium. The end-point impact assessment method focuses on the damage inflicted at the end of the “cause-effect” chain (Park et al., 2016). In ReCiPe, three uncertainty perspectives are used to evaluates the life cycle impacts which are the individualistic perspective, the hierarchist perspective, and the egalitarian perspective (Goedkoop et al., 2009). Out of these three perspectives, the egalitarian perspective, which takes into account all impact pathways with the longest time frame, will be used in this study. Moreover, while the ReCiPe method considers three damage categories in the end-point level namely, human health damage, damage to ecosystems, and resource scarcity, the human health damage category was selected as a social LCA indicator in this study. In this context, the results of mid-point indicators, connected to the human health damage category, have been investigated to observe the extent to which these indicators have affected the end-point indicator result (Table 2).

For every specified magnitude of the consumed materials, energy, or waste determined in the LCI step, the SLCIA calculations were carried as follow:

1- Select the mid-point characterization factors (CF_m) for the respective mid-point indicators from the ReCiPe Midpoint (E) list in the Ecoinvent v3.7 database, where (E) is referred to as the egalitarian perspective.
2- Determine the end-point characterization factors (CFe) according to Eq. (1):

$$CFe = CFm \times F_{M \to E} \tag{1}$$

where $F_{M \to E}$ is the mid-point to end-point conversion factors obtained from the ReCiPe 2008 report (Goedkoop et al., 2009). The factors are as listed in Table 2.

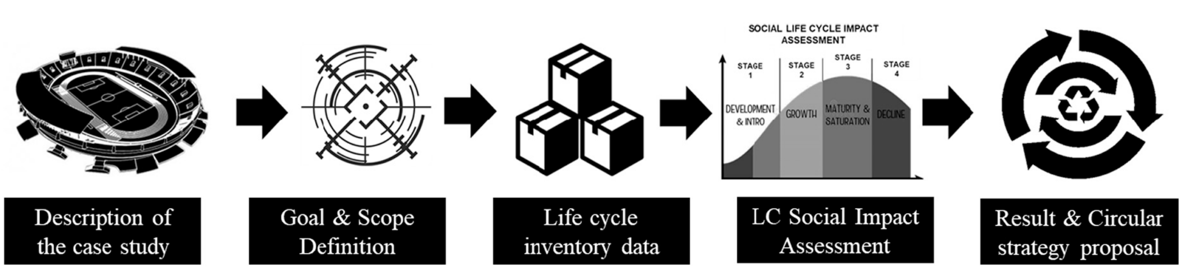


Fig. 1. The analysis workflow.

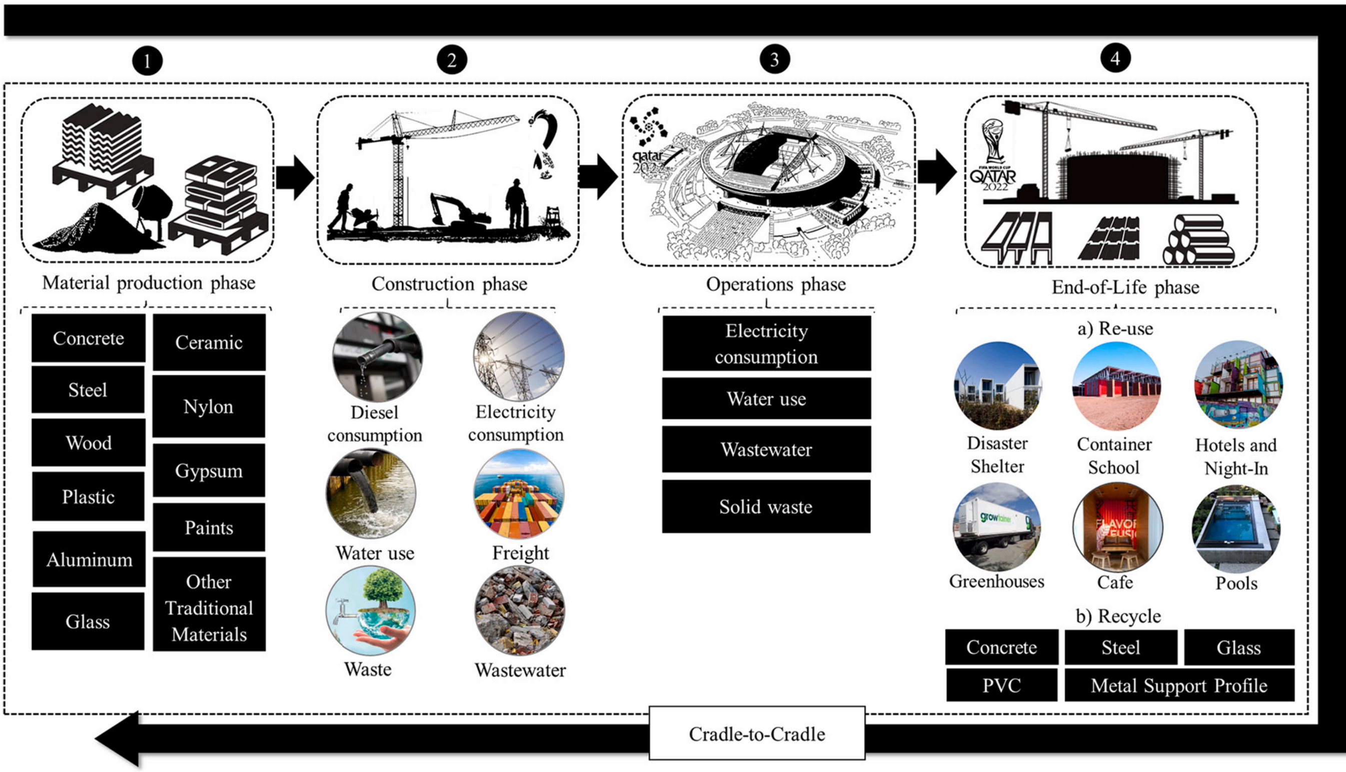


Fig. 2. Life cycle stages and system boundary used for the RAA stadium assessment.

3- Calculate the damage to human health in the unit of "disability-adjusted life years" (DALY) according to Eq. (2):

$$Damage\ (DALY) = CFe \times Q \tag{2}$$

where Q is related to the used quantities listed in Table S1. Details about the selected mid-points and end-point indicators are shown in Table 2.

3.5. End-of-life scenario

Building and construction materials subject to proper environmental waste (e-waste) management and treatment strategies post demolition can find use in building similar structural units. Several materials used in the construction of Ras Abu Aboud stadium can be reused once dismantled, post the 2022 event to build various sporting facilities overseas. Thus, a prognostic scenario assessment is carried out to understand the end-of-life phase of RAA stadium from a CE perspective. Optimistic and Pessimistic scenarios were studied in brief, where the optimistic scenario takes into account the best possible alternatives that can be applied to the case of stadium construction end-of-life, most applicable in the case of RAA stadium; and, the pessimistic scenario that brings out the worst-case alternative in terms of waste treatment. The optimistic scenario considers the best-referenced e-waste treatment channels for materials that show a significantly high impact on human health that was used for the Ras Abu Aboud stadium. LCIA was performed using the Eco-invent v3.7 database for the EoL scenario. The results aid in understanding the benefits of reuse and recycle in comparison to the extraction of new materials for future use. From literature, assumptions were made for the pessimistic scenario considering all possible e-waste treatment alternatives for the selected units of measure, with a possibility of relativity low damage to human health impact. The percentage contribution across each impact category can be in Section 4.1. The end-of-life scenarios based on possible e-waste treatment alternatives are presented in Table 3.

Several studies have shown a "medium-to-low" potential for the reuse of concrete due to several deconstruction difficulties. Reclaimed and prefabricated concrete panels account for only 23.3% of reuse in construction projects (Hradil et al., 2014). However, RAA stadium currently uses concrete beams and columns that are from reclaimed and prefabricated materials. These are pre-cast units that were manufactured overseas and then brought to Qatar, which can be dismantled with minimal to no wastage after the event, to be fully reused as "readymade" units in similar constructions in future. From an optimistic point of view, crushed concrete has a high grade of applicability when it comes to the use of crushed concrete as an aggregate in Portland cement (Public works technical bulletin, 2004). Nearly, almost all the steel used in the stadium construction can be put to recycling. 98% of the structural steel and metal-support profiles used for low rise-to-medium rise buildings and monuments are recycled (Blander, 2019). This aptly fits the profile of RAA stadium's "end-of-life" scenario. While only 71% of the metals used as reinforcing materials in concrete structures are recycled due to sorting difficulties. Studies have also shown energy-saving benefits when attempting to recycle premium quality window glass by 25% (Kasper, 2006). These recycled premium quality glass can be used in other upcoming construction projects within the state. The energy saved can support the carbon-neutrality goals of Qatar's construction sector as a whole once the stadium is dismantled. On the other hand, contaminated glass can also be recycled to be used as grit for sandblasting. PVC thermoplastic sheets can be recovered from landfills to be used in "waste-to-energy" plants (Modern Building Alliance, 2018). For every specified magnitude of the consumed materials, energy, or waste determined in the LCI step, the SLCIA calculations were carried out using Eqs. (1) and (2) to find the potential impacts on human health in the End-of-life scenario. The total savings from the end-of-life stage due to recycling and reuse strategies specified in Table 3 were also calculated. The net benefits for the end-of-life phase were calculated as the avoided damage due to the reuse of RAA stadium's materials in other facilities instead of producing new materials. For example, reusing 1 kg of RAA stadium's steel in another facility will prevent the production of 1 kg of virgin steel. For the same, the materials that were contributing

Table 1
Life cycle inventory data of RAA stadium.

Materials/ Activities	Category	Virgin amount used	Recycled amount	Unit	Activity name in ecoinvent v3.7
Raw material phase					
Concrete	Concrete	2.41E+08	6.97E+06	kg	Concrete block production
Earthworks	Fill	0.00E+00	3.69E+05	kg	
Base plaster	Finishes	2.51E+05		kg	Base plaster production
Ceramic tiles	Finishes	1.80E+04		kg	Ceramic tile production
Epoxy resin	Finishes	3.59E+05		kg	Epoxy resin production
Gypsum board	Finishes	1.33E+06		kg	Gypsum plaster board
Nylon product	Finishes	2.69E+05		kg	Nylon 6 production
Paint	Finishes	5.61E+04		kg	Alkyd paint production, white, solvent-based, product in 60% solution state
Polypropylene fabric	Finishes	2.04E+05		kg	Textile production, nonwoven polypropylene, spun bond
Stone plate	Finishes	2.58E+05		kg	Natural stone plate production
Vinyl floor	Finishes	8.78E+04		kg	Market for vinyl chloride
Coatings to Steelwork	Finishes	1.94E+07		kg	Coating powder production
Intumescent Fire Protection	Finishes	8.41E+05		kg	Cellulose fibre production
Containers Stairs	Finishes	1.28E+07		kg	Hot rolling, steel
Average metal pipe product	Metals	8.67E+05		kg	Drawing of pipe, steel
Steel	Metals	3.91E+07	1.24E+07	kg	Reinforcing steel production
Average metal product	Metals	6.60E+07		kg	Market for aluminum oxide, metallurgical
Glass	Openings	1.19E+06	1.80E+05	kg	Flat glass production, uncoated
Wood door	Openings	1.01E+05		kg	Plywood production
Mineral pipe insulation	Other	1.58E+06		kg	Tube insulation production, elastomere
Plastic and Metal	Other	5.72E+04		kg	Extrusion, plastic pipes
Polyethylene foam	Other	6.27E+04		kg	Market for polyurethane, rigid foam
Pitch	Other	2.05E+06		kg	Market for pitch
PVC thermoplastic sheet	Thermal & Moisture	1.80E+06	2.17E+05	kg	Polyvinylchloride production, bulk polymerization
Construction phase					
Diesel		6.92E+05		kg	Diesel production, petroleum refinery operation
Total electricity consumption		8.94E+06		kWh	Market for electricity, high voltage
Water use		6.37E+04		m^3	Market for tap water
Freight		6.87E+08		tkm	Market for transport, freight, inland waterways, barge
Waste generation		8.26E+08		kg	Market for inert waste
Wastewater		2.23E+04		m^3	Market for wastewater, average
Operation phase					
Electricity and cooling total		4.38E+06		kWh	Market for electricity, high voltage
Water use		1.90E+04		m^3	Market for tap water
Waste generation		1.75E+03		tons	Market for municipal solid waste
Wastewater		8.64E+03		m^3	Market for wastewater, average
End-of-Life phase					
Average metal product	Finishes		6.60E+07	kg	Treatment of metal scrap, post-consumer, prepared for melting
Concrete	Concrete		2.41E+08	kg	Treatment of waste concrete, not reinforced, recycling
Mineral pipe insulation	Others		1.58E+06	kg	Treatment of metallic and mineral pipes, mixed, for recycling, sorting
Steel	Metals		3.91E+07	kg	Treatment of waste steel, recycling
PVC thermoplastic sheet	Thermal & Moisture		1.80E+06	kg	Treatment of waste PVC product, thermoplastic sheet

Table 2
ReCiPe mid-point and end-point indicators were used in this study.

Mid-point impact category	Mid-point to end-point conversion factors	Unit	Damage category	Unit
Climate change (CC)	3.51×10^{-6}	DALY/ kg CO_2-eq	Human health	DALY
Human toxicity ((HT)	7×10^{-7}	DALY/ kg 1,4-DCB eq		
Ionizing radiation (IR)	1.64×10^{-8}	DALY/ kg U-235 eq		
Ozone depletion (OD)	1.76×10^{-3}	DALY/ kg CFC-11 eq		
Particulate matter formation (PMF)	2.6×10^{-4}	DALY/ kg PM_{10} eq		
Photochemical oxidant formation (POF)	3.9×10^{-8}	DALY/ kg NMVOC		

highest to the human health impact in the production of raw material phase were considered. Materials that contributed least to the human health impact under the production of raw material phase were excluded due to the negligible or no change in net savings when subject to recycle for possible reuse in construction projects, so as to preserve circularity. The a impact of to show how RAA stadium from a cradle-to-cradle perspective can be seen as the most sustainable stadium design inflicting low damage to human health, preserving social sustainability and circularity themes in construction.

4. Results and discussion

4.1. Social LCA: A cradle-to-cradle perspective

In the results section, the mid-point impact indicator results will be highlighted first, then the resulted damage to human health end-point will be evaluated. Moreover, the key materials, processes, activities, and life stages that significantly contribute to the social impact of RAA stadium will be identified and analyzed to draw conclusions and make

Table 3
End-life-scenarios.

Units	e-waste treatment alternatives	Optimistic	Pessimistic
Metal support -profile	Dismantling and recycling	100% recycling with source-segregation and sorting of waste tinplate, ferrous metal, and aluminum from residues.	a) 71% recycled for one's used as reinforced material. b) 92% recycled avoiding landfills.
Steel	Endless recycling	100%	98%
Concrete	Reuse/Recycle	100% crushed and stockpiled.	23.3% total reuse and landfill
Glass	Recovery and glass furnace recycling	a) Recycling cullet to flat glass furnace. b) Grit for sandblasting	Landfill
PVC Thermoplastic sheet	Incineration with energy recovery	100% reuse	a) Landfill recovery for recycle/reuse b) Incineration with sorting loss

recommendations for possible areas of improvement in the future. In the analysis, 2 scenarios were introduced for the operation phase to identify the avoided burden when dismantling the stadium post event and to explore the benefits associated with modular construction. The 1st scenario considered dismantling the stadium after a year of operation, which is the proposed case of RAA Stadium. The 2nd scenario considered dismantling the stadium after 50 years of operation, a scenario considering practical lifespan of traditional stadiums. Such scenario-based analysis were carried out to understand the true essence of demountable stadiums in terms of their benefits on environment and socio-economic pillars once dismantled immediately after the sporting event. At the mid-point level, it is apparent from the data in Fig. 3a that the production phase acts as the first contributor out of all phases across the six impact categories, followed by the construction phase with a much lower contribution. Whereas no evident contribution can be noticed for the operation phase. A possible explanation for this might be related to the limited number of sports events that take place annually. This is beside the rest and the preparatory periods of sporting teams that lie in between the competitions period, during which the football stadiums aren't operated. Data from Fig. 3a can be compared with the data in Fig. 3b which considers the second scenario of the operation phase. In the second scenario, the operation phase became the second-highest contributor across the 6 impact categories with considerable contributions of 42.9%, 35.6%, 37.6%, 34.5%, 46.2%, and 18.1% on CC, HT, IR, OD, PMF, and POF, respectively. What is striking about Fig. 3a and b is that they show negative contribution, which corresponds to remarkable savings across the six mid-point impact categories due to the planned circularity activities of repurposing several materials at the end life of the stadium to cover some of the societies' needs without producing new materials from the same type.

To better understand the impact of the production, the construction, and the operation life cycle stages on the specified mid-point indicators, the percent contribution of each activity under each life stage is shown in Fig. 3c, d, and e, respectively. In the production phase, it can be seen from Fig. 3c that the average metal product, coatings to steelwork, steel, and concrete are the most influential materials across the six mid-point indicators. On the other hand, the contribution of the remaining materials was marginal and ranging from 0 to 2%. The average metal product in this study was referred to (aluminum oxide, metallurgical), which had the highest contribution of 53% on HT, while it was ranging between 15% to 38% for the rest of the categories. The high contribution to HT is attributed to the high toxicity characterization factor of 76.09 kg 1,4-DCB eq/kg, which was assigned by the ReCiPe method. A 1:1 mixture of epoxy and polyester resin was assumed for the coatings to steelwork. The coatings were responsible for 51%, 39%, 36%, 34%, 31%, and 24% for IR, OD, POF, CC, PMF, and HT, respectively. In comparison to the average metal product and the coatings to steelwork, the contribution of steel and concrete on the six impact categories were significantly lower and ranging from 12% to 19% and 3% to 8.5%, respectively.

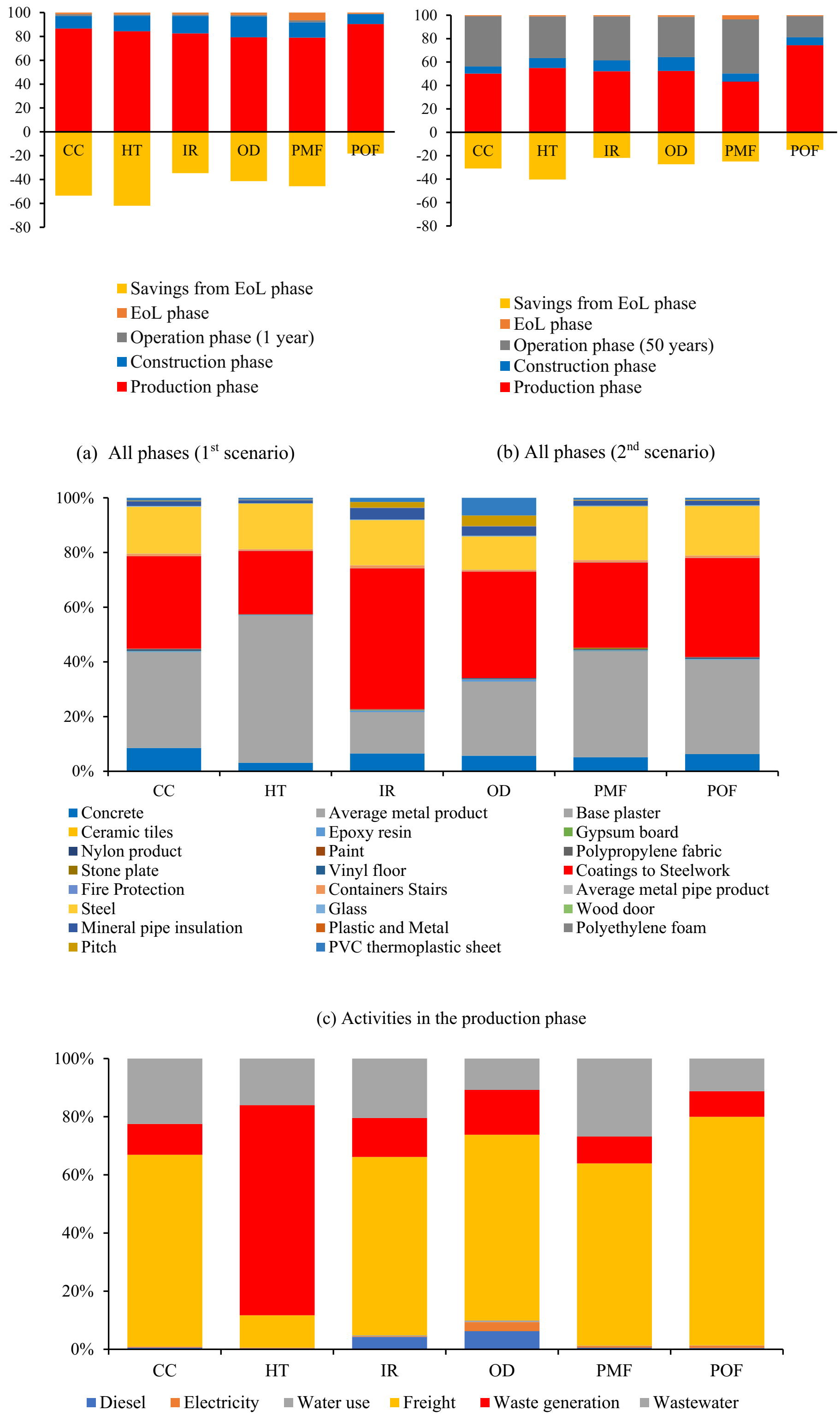
In the construction phase, from Fig. 3d, it can be seen by far that the greatest contribution is for the construction materials that have been freighted through ships, where the contributions were over 60% for the CC, IR, OD, PMF, and POF, however, only 11% contribution was revealed for the HT. In contrast, the generated waste highlighted the highest contribution to HT with 72%, but the range of contribution was from 8% to 15% for other mid-point indicators. The generated wastewater yielded a contribution range of 20% to 26% on IR, CC, PMF, and a range of 10% to 16% on OD, POF, and HT. Moreover, the diesel revealed a lower contribution for both the IR and OD with 4% and 6%, respectively. By contrast, the six mid-point indicators appeared not to be affected by the water use activity.

In Fig. 3e, it can be seen that the annual wastewater generation in the operation phase reported significantly more contribution to the six mid-point impact categories than other activities in the same phase. Additionally, the annual waste generation activity was noticed to have the second-highest contribution on the HT, PMF, and POF with 24%, 18%, and 10%, respectively. Another finding to emerge from Fig. 3e is that the consumed electricity demonstrated 32%, 26%, and 8% impacts on the CC, OD, and POF, respectively.

At the end-point level, after analyzing the impacts of the stadium's life stages on the six mid-point impact categories, the relative damage contribution of each life stage to human health is illustrated in Fig. 4. It is seen from Fig. 4a and b that the majority of impacts on human health end point were from the production phase with a corresponding DALY value of 8207.5. The damage to human health from the construction phase was found to be significantly lower than that of the production phase by 85% with a DALY value of 1218. This is expected because in the production phase all up-stream activities were included like raw material extraction and energy consumption in the manufacturing processes, which all responsible for a wide range of harmful emissions. Fig. 4 is quite revealing as it shows the human health damage that was avoided due to the incorporation of recycled materials in the production phase, which was estimated to be 285.4 DALY, of which 95.8% was due to the use of recycled steel material with a quantity of 1.24E+07 kg. Further analysis showed that for the operation phase, only 1.14% of the contribution to the total damage to human health was assigned to one year of operation (Fig. 4a), while over 30% of the total damage was assigned to 50 years of operation (Fig. 4b). Overall, the total damage to human health, expressed in DALY, was estimated to be 9539.9 DALY in the first scenario, while it was estimated to be 15,145.5 DALY in the second scenario as shown in Fig. 5. This dramatic difference between the two scenarios is one of the main striking outcomes in this study owing to the avoided human health damage induced from electricity consumption, and municipal solid waste and wastewater generation for 49 years of operation that corresponds to 5605.6 DALY. Another interesting aspect of Fig. 5 is the net benefits of end-of-life management, were due to the reusing and recycling of several materials mentioned in Table 3, the resulted savings was estimated to be 5822.1 DALY, which is equivalent to 61% and 38.4% reduction of the total human health damage in scenario 1 and 2, respectively.

4.2. Sensitivity analysis

A sensitivity analysis was conducted to further analyze the most



(a) All phases (1st scenario) (b) All phases (2nd scenario)

(c) Activities in the production phase

(d) Activities in the construction phase

Fig. 3. Percentage contribution on each mid-point impact category.

sensitive impact categories across each life cycle stage and compare them for possible volumetric variations under a probabilistic scenario. Montecarlito v1.10 package was used to conduct the sensitivity analysis. The sensitivity analysis can identify the degree of impact on a given environmental indicator if an input is changed in terms of the type or amount of the materials used. A possible increase or decrease in the impact across each environmental impact category may/may not result in possible variations in the end point human health impact. Considering the various sensitivity of environmental impact categories can support in optimizing the use of certain predominant materials with an aim to

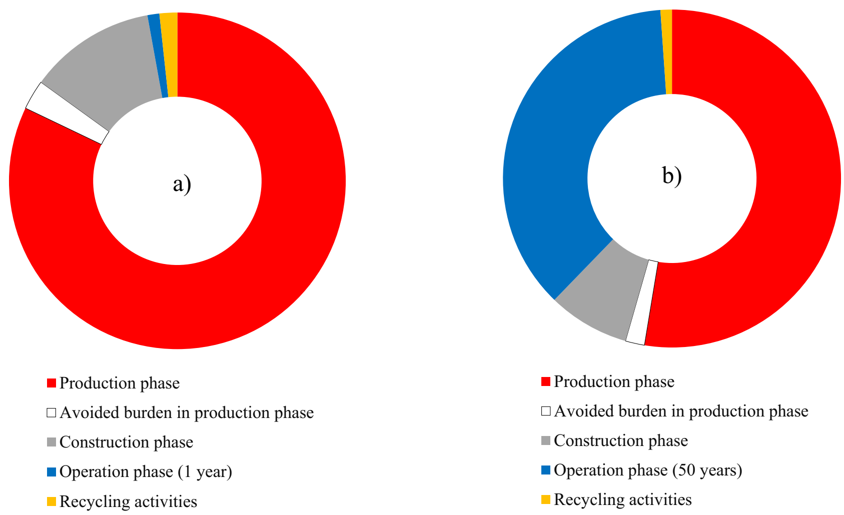


Fig. 4. Percent contribution of each phase to the human health end-point: (a) 1st scenario (1 year of operation); (b) 2nd scenario (50 years of operation).

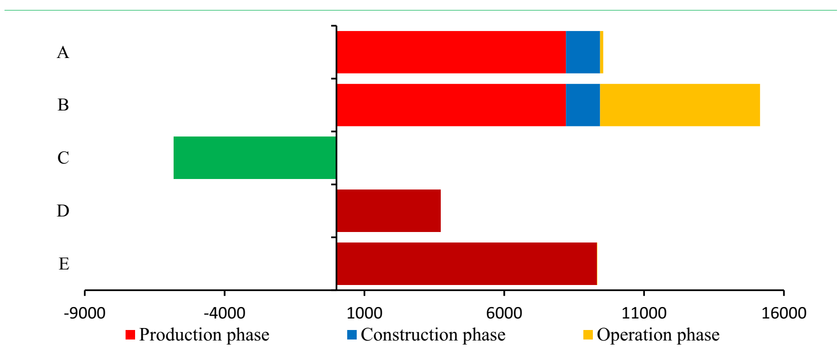


Fig. 5. Total human health impacts of A) Scenario 1; B) Scenario 2; C) net savings from EoL phase; D) Net impact in Scenario 1; E) Net impact in Scenario 2 (expressed in DALY).

reduce the potential environmental impact and thus, the impact on human health. According to the percentage contribution of components in each LC phase across independent impact categories, the highest contributing components were chosen as the variables in the analysis, subject to volumetric changes. The volumetric changes in each material across the life cycle stages resulted in possible variations in the sensitivity levels for each environmental impact category taken into account throughout the study. The sensitivity level for each mid-point impact category was identified by increasing and decreasing the material quantity by ±0%, ± 10%, ± 20%, and ± 30%. In the production of raw material phase, the materials including concrete, average metal product, coatings to steelwork upper floors, steel and mineral pipe insulation were considered as the input data due to their high percentage contribution across the impact categories. The volumes of these inputs were then changed to understand the sensitivity level keeping other materials constant. Other materials were not considered for volumetric changes due to their negligible contribution to the environmental impacts. Results for volumetric changes on material quantity in the production of the raw material phase can be seen in Table 4. The trends with the volumetric changes are illustrated in Fig. 6. Taking the slope of each curve, we can see that human toxicity is the most sensitive impact category in this life cycle phase followed by climate change, particulate matter formation, ionizing radiation, photochemical oxidant formation, and lastly ozone depletion as the least sensitive impact category.

In the construction phase (Table 5), the volume of waste per kg and freight were changed proportionally, keeping wastewater, total power used in Kwh and, water use values unchanged. While observing the slope of the curves from Fig. 7a, it can be seen that human toxicity is most sensitive to volumetric changes. This trend is followed by climate change, particulate matter formation, photochemical oxidant formation, ozone depletion, and finally ionizing radiation, classed as the least sensitive environmental impact category.

Table 4
Results for volumetric changes on material quantity in the production of raw material phase.

Impact category	−30%	−20%	−10%	0%	10%	20%	30%
Climate change	9.95E+02	1.13E+03	1.27E+03	1.40E+03	1.54E+03	1.68E+03	1.81E+03
Human toxicity	4.61E+03	5.25E+03	5.89E+03	6.53E+03	7.17E+03	7.81E+03	8.45E+03
Ionizing radiation	2.38E-01	2.70E-01	3.03E-01	3.36E-01	3.68E-01	4.01E-01	4.34E-01
Ozone depletion	3.98E-02	4.52E-02	5.07E-02	5.62E-02	6.17E-02	6.71E-02	7.26E-02
Particulate matter formation	1.92E+02	2.18E+02	2.44E+02	2.70E+02	2.96E+02	3.22E+02	3.48E+02
Photochemical oxidant formation	5.29E-02	6.01E-02	6.73E-02	7.45E-02	8.16E-02	8.88E-02	9.60E-02

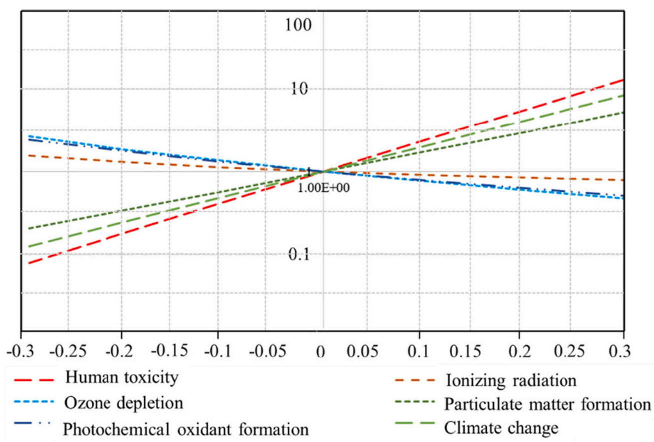


Fig. 6. Sensitivity analysis results for impact categories with volumetric changes in the production of raw material phase.

Similar to the above two phases, the volume of wastewater, water use and, electricity and cooling were changed by ±10%, ± 20%, and ± 30% in the operations phase of the RAA stadium S-LCIA results. The rest of the elements were kept constant. Results for volumetric changes on material quantity in the operations phase of the LC are shown in Table 6. The volumetric changes demonstrated climate change as the most sensitive environmental impact category followed by human toxicity, particulate matter formation, ozone depletion, ionizing radiation, and finally photochemical oxidant formation as the least sensitive impact category across the operations phase of the life cycle. These trends can be observed from Fig. 7b.

4.3. Reimaging legacy post-FIFA 2022

Circular economy practices can reshape the event design to deliver long-term socio-economic benefits to the host city and its neighbors before, during, and after the FIFA World Cup 2022. This section deals on how sustainability and innovation in modular stadium designs can bring long-lasting legacy post-event, through reuse and recycling from a socio-economic perspective. Demounting the modular infrastructure of Ras Abu Aboud stadium for possible reuse alternatives is considered the most viable strategy in bringing out the essence of post-event legacies of the World Cup™ 2022 tournament.

The demountable shipping containers used in Ras Abu Aboud stadium act as elementary units for several aesthetically pleasing reuse alternatives in real-time applications for sustaining possible future legacies, a pan-Asian legacy initiative of FIFA World Cup 2022™. Panning out the use of shipping containers post-event helps in cutting down the

Table 5
Results for volumetric changes on material quantity in the construction phase of the life cycle.

Impact category	−30%	−20%	−10%	0%	10%	20%	30%
Climate change	9.35E+01	1.07E+02	1.19E+02	1.32E+02	1.45E+02	1.58E+02	1.71E+02
Human toxicity	5.93E+02	6.77E+02	7.61E+02	8.44E+02	9.28E+02	1.01E+03	1.10E+03
Ionizing radiation	1.03E+00	1.04E+00	1.04E+00	4.74E-02	5.21E-02	5.68E-02	6.15E-02
Ozone depletion	8.21E-03	9.20E-03	1.02E-02	1.12E-02	1.22E-02	1.32E-02	1.42E-02
Particulate matter formation	2.25E+01	2.57E+01	2.88E+01	3.19E+01	3.51E+01	3.82E+01	4.13E+01
Photochemical oxidant formation	1.23E-02	1.40E-02	1.57E-02	1.74E-02	1.91E-02	2.08E-02	2.26E-02

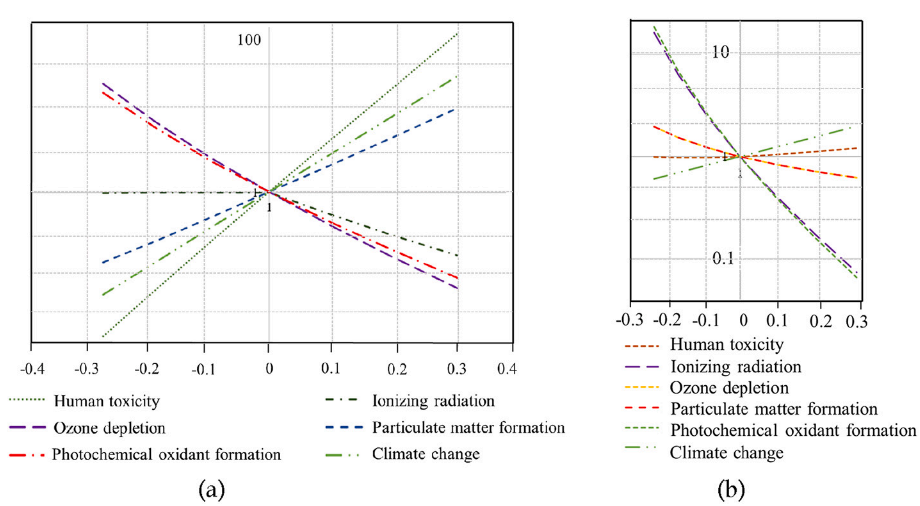


Fig. 7. Sensitivity analysis results for impact categories with volumetric changes across a) construction phase b) operations phase of the life cycle.

Table 6
Results for volumetric changes on material quantity in the operations phase of the life cycle.

Impact category	−30%	−20%	−10%	0%	10%	20%	30%
Climate change	5.46E+00	6.22E+00	6.99E+00	7.76E+00	8.53E+00	9.29E+00	1.01E+01
Human toxicity	1.03E+00	1.18E+00	1.32E+00	1.47E+00	1.61E+00	1.76E+00	1.90E+00
Ionizing radiation	9.13E-05	1.04E-04	1.17E-04	1.30E-04	1.44E-04	1.57E-04	1.70E-04
Ozone depletion	1.49E-04	1.70E-04	1.92E-04	2.13E-04	2.34E-04	2.55E-04	2.76E-04
Particulate matter formation	1.06E-01	1.21E-01	1.36E-01	1.51E-01	1.66E-01	1.81E-01	1.96E-01
Photochemical oxidant formation	6.10E-05	6.97E-05	7.83E-05	8.70E-05	9.57E-05	1.04E-04	1.13E-04

global carbon footprint from the construction sector, supporting the United Nations Urban Agenda 2030 and 2016 Paris Agreement. It is important to align the possible re-use alternatives of shipping containers with the FIFA World Cup post-event strategies and United Nations 2030 Sustainable Development Goals (UN SDGs) to bring the essence of a truly sustainable World Cup event with an ever-lasting legacy from the eye of circularity. The authors have mapped possible reuse alternatives of steel shipping containers with Qatar's Supreme Committee (SC) vision of rethinking legacy to understand how well these alternatives support harmonizing SDGs post-World Cup (Table 7).

Qatar has firmly believed in the power of education, a pillar of Qatar National Vision 2030, and supports knowledge management partnerships (SDG 17) to spread quality education in the region and around the globe. The use of shipping containers dismantled from Ras Abu Aboud stadium to construct modular schools supports this vision and can contribute to many SDGs such as quality education (SDG 4), climate action (SDG 13), and sustainable cities and communities (SDG 11). The use of steel shipping containers as sports facilities can also contribute to many SDGs such as innovation (SDG 9), climate change mitigation due to sustainable construction practices (SDG 13), and responsible production and consumption (SDG 12). The Zed Sheikh Zayed sports facility in Cairo, Egypt is an example of a groundbreaking project put together using 16 shipping containers placed in an aesthetic design. While, green libraries are icons of a sustainable future and support building a community that can reshape the pursuit of knowledge in the areas of climate disruption (SDG 13), resilience (SDG 3), and liveability (SDG 11; SDG 3) for better outreach. Innovative and sustainable aesthetic designs using shipping containers align the library's core values in bringing life to equitable choices in a call to action for quality education (SDG 4). Alternatively, the use of refurbished shipping containers as refugee shelters acts as temporary housing solutions for disaster struck victims (SDG 3; SDG 11; SDG 15) in countries like Indonesia, Japan, Philippines, and India. Refugee shelters are often community-driven (SDG 10). This can support the social aspects of mental stability and recovery process post-natural disasters due to the cohesive nature of interactive living (SDG 11). Whilst, speaking of temporary housing facilities, refurbished shipping containers are an excellent choice for aesthetically pleasing permanent residential units. A great example of the magnificent conglomeration of 14 shipping containers is the PV14 modular house in Dallas, United States. Such modular houses are sustainable alternatives to construction and can support post-event legacy for FIFA 2022 World Cup™ under the sustainable communities and societies goal (SDG 11) of United Nations. Several other post-game usages of the containers with possible innovative business ideas such as education, hospital, shops, food production units, cafes, bridge, residential units, hotels, public restrooms, and storage facilities are presented in Table 7.

The FIFA world Cup 2022 and Ras Abu Aboud stadium can leave a long-term impact on sustainability through circular and sharing economy applications of reuse, recycle and re-allocation of resources. The initiatives of Qatar to distribute the shipping containers to neighboring countries for possible business innovations can strengthen the partnership goals. This creates a new market for sharing resources and the judicious use of assets in an organic manner, giving rise to a paradigm "sharing economy". Such sharing initiatives help in bringing circularity practices with collaborative consumption patterns, eliminating waste and cutting down new variables of concern to the equation of sustainability. As per previous studies, the Sharing economy is positively contributing to have sustainability solutions worldwide, either directly or indirectly. The sharing economy advocates positive environmental influence (e.g., reduction of Greenhouse Gas, fuel consumption, etc.), commercial benefits (i.e., subordinate expenses, market expansion, etc.), and social corporate responsibility (i.e., better community interactions, work availability, customer satisfaction, etc.) (Schor, 2016), (Gonzalez-Padron, 2017). The possible use of shipping containers to build schools, disaster shelters, childcare centers, sports and training facilities etc. in other countries all support in monetizing existing assets post event. According to the findings by Kutty et al. (2020a), resource-sharing strengthens transboundary partnerships and are catalyzers that can help in harmonizing most of all possible SDGs. This is well evident in the case of Qatar's world cup post-event initiative. Thus, circular economy strategies along with sharing economy principles in construction projects tailored for mega-sporting events can support reimaging the legacy for sustainable outcomes.

5. Conclusion and future works

This research is the first of its kind to conduct a full S-LCIA for reusable container stadiums tailored for the FIFA World Cup mega-events, taking the case of RAA stadium in Qatar. This study investigated the impacts of utilizing materials, energy, water, and waste on human health under a CE model using the cradle-to-cradle approach. The study commenced with data collection for a thorough system boundary starting with material production, followed by construction and operation phases, ending with end-of-life management to assess the potential social impacts associated with all life cycle phases on the endpoint damage category of human health. Ecoinvent v3.7 life cycle impact database using the ReCiPe model was employed to calculate the endpoint impact values for the human health category.

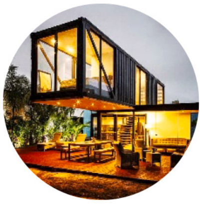
Results have shown that the production phase was responsible for the highest contribution to the total damage to human health, whereas the construction phase was responsible for significantly lower damage to the end point impact "Human health". In comparison to the first case scenario of 1 year of operation, much higher damage was induced from the second case scenario. Based on the S-LCIA results, it was seen that 3% of the total social burden, was avoided due to the use of recycled materials in the construction of the RAA stadium.

A possible end-of-life scenario was also presented in this research. An interesting outcome that resulted from carrying end-of-life management was the significant reduction in the damage to human health, which was estimated to be 5822.1 DALY. The sensitivity analysis revealed human toxicity as the most significant impact category for possible percentage variations across the production of raw material and construction phase. While, climate change was the most sensitive impact indicator in the operations phase, subject to volumetric variations in the quantity of energy used.

A further reflection of the research findings shows that negative human health impacts can be reduced by various strategies like using some examples of alternative low-energy materials, applying prefabrication to reduce construction emissions, and end-of-life recycling. In this regard, many studies have discussed the applicability of sustainable alternatives, for instance, concrete can be substituted by using blended cement that contains a high volume of cementing complementary materials. Whilst, recycling and reuse of steel and metals can result in considerable savings of energy; see (Reddy, 2009; Hertwich et al., 2019). Additionally, a shift towards sustainable construction and environmental preservation can be embraced by a circular model or approach for end-of-life materials recycling. The wastewater from the stadiums during the event can be treated and reused in the district cooling plants and for possible irrigation purposes within the State as an end-of-life management strategy. This ensures proper utilization of existing resources to support the zero-waste initiatives of Federation Internationale de Football Association during mega events.

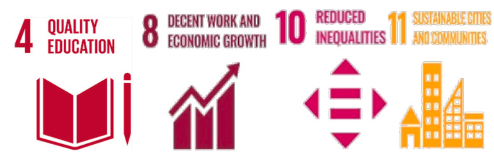
RAA stadium being a reusable container stadium can be dismantled and brought back to the picture at ease in relation to the traditional tip-to-toe construction, where the stadium design acts as a blueprint for any sustainable mega event across the globe in the future. The authors suggest the use of "attributional LCA " an ISO 14040:2006 standardized tool to better understand the system flows when using a cradle-to-cradle approach. A "hybrid-LCA model" combining "process-LCA" with "input-output approach" is well suggested to identify the embodied socio-economic and environmental impacts of stadium construction projects considering the regional, national, and global impacts. A full-LCA model

Table 7
Strategic mapping for post-event container use strategy with UN-SDGs and FIFA 2022 World Cup™ vision.

Design innovation alternatives	FIFA post-event strategy alignment	Indicators for harmonizing sustainability targets	Examples	SDG Alignment
 Residential units	• Improve economic infrastructure through the efficient use of available resources. • Design and construct sustainable units according to national and international standards.	11.3.2 City planning strategies with tech-driven urban planning initiatives. 13.b.1 Infrastructure units set up per effective climate-change mitigation planning 15.9.1 Progress towards "Aichi Biodiversity Target 2".	Hive modular living spaces -Minnesota, U.S Manifesto House, Curacavi, Chile	11 SUSTAINABLE CITIES AND COMMUNITIES 13 CLIMATE ACTION 15 LIFE ON LAND
 Cafeteria	• Generate business post-event with available infrastructure and services. • Sustainable investment through business initiatives	8.2.2 Share of employment in the service sector concerning the total employment. 9.3.1 Share of small-scale industries contributing to total industrial value-added. 12.3.1 Food loss index.	Starbucks Coffee House, Taiwan	2 ZERO HUNGER 8 DECENT WORK AND ECONOMIC GROWTH 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 12 RESPONSIBLE CONSUMPTION AND PRODUCTION
 Modular Hotels	• Sustainable economic diversification in the hospitality sector during, before & after World Cup • Post-tournament asset use	2.1.2 Prevalence of food insecurity concerning the available food distribution units in the country. 3.d.1 International health regulation compliance for "produce" and "use" initiatives. 8.9.2 Jobs in hospitality industry per total employment 11.b.1 Sustainable tourism strategies	Hotel WineBox Valparaiso, Chile Seven Havens hotel, Lombok, Indonesia Warnemunde dock Inn, Germany	2 ZERO HUNGER 3 GOOD HEALTH AND WELL-BEING 8 DECENT WORK AND ECONOMIC GROWTH 11 SUSTAINABLE CITIES AND COMMUNITIES
 Disaster shelter	• Inclusiveness • Sustainable infrastructure • Contribution to economic prosperity	1.5.2 Economic loss as a result of natural calamity in relation to GDP 11.1.1 Share of population with improper shelter facilities and inadequate living standards. 11.7.1 Build-up areas accessible for victims struck by disaster.	Shingeru Ban Architects Disaster Relief Project, Japan	1 NO POVERTY 3 GOOD HEALTH AND WELL-BEING 11 SUSTAINABLE CITIES AND COMMUNITIES 15 LIFE ON LAND
 Container Bridge	• Sustainable infrastructure • Post-tournament asset use	9.4.1 Emissions per value-added 11.7.1 Share of sustainable built-up areas for public use	Ariel Sharon Park Tel Aviv, Israel	9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 11 SUSTAINABLE CITIES AND COMMUNITIES
 Portable Libraries	• Work-integrated knowledge transfer platforms for education and training through Qatar National Vision 2030. • Promote efficient solutions for reduced impacts through sustainable construction	4.4.1 Share of the population having minimum proficiency in reading. 9.3.1 Institutional operationalization as a proportion of industry value-added.	BiebBus, Netherlands	4 QUALITY EDUCATION 8 DECENT WORK AND ECONOMIC GROWTH 9 INDUSTRY, INNOVATION AND INFRASTRUCTURE 11 SUSTAINABLE CITIES AND COMMUNITIES
	• Conservation of biodiversity.	7.b.1 Share of investments devoted to	CropBox, Mississippi, U.S	

(continued on next page)

Table 7 (*continued*)

Design innovation alternatives	FIFA post-event strategy alignment	Indicators for harmonizing sustainability targets	Examples	SDG Alignment
 Freight Farms	• Adapting efficient technology and smart initiatives to reduce environmental impacts. • Sustainable building units • Environmental stewardship	mobilizing sustainable energy usage through technology interventions. 15.b.1 Rate of development progress concerning the sustainable use of the ecosystem.		
 School	• Education and empowerment of youth. • Providing physical and mental education to a diversified community.	4.a.1 Share of schools with effective learning opportunities. 8.6.1 Employment rate in the education and training sector	Waldorf Costa Mesa School, California-U.S	

integrated with the "life cycle costing approach" is also suggested to quantify the economic costs along with the environmental impacts. A probabilistic weighted likelihood estimation can be used to model the end-of-life scenarios, where the weights assigned to each unit are a statistical distribution and a range of values can be obtained for each pessimistic, baseline, and optimistic scenario by varying the likelihood value. However, complexities arise as the number of units in the end-of-life approximation increases. The shipping containers utilized in the RAA stadium can be reused for various applications. To give an instance, locally the containers can be applied in the growing trend of urban farming for ecological food production, as retail units, temporary storages, etc. More value can be earned from shipping the containers to other countries, especially with high refugee and low-income populations, to be adapted for affordable housing projects, schools, and mobile healthcare units.

The significance of the results highlighted in this article comes from Qatar's commitment to provide a carbon neutral mega event through modular construction and innovative stadium designs, a pillar of FIFA's sustainability strategy. The use of circularly approach in demountable stadium construction has gained benefits (reduced environmental burden) compared to the standard construction methods for stadiums. This itself is a win for the oil rich nation of Qatar in joining hands to support the Qatar National Vision (QNV 2030), the Paris Agreement of 2015 for safe earth and the United Nations 2030 Urban Agenda. The collaborative practices of sharing shipping containers and stadium grounds post event creates economic value by providing access and intensifying the use of underutilized assets. Future investigations on sharing economy concept for the re-use of shipping containers can be done by conducting footprint assessments on the net carbon sequestration and emission reduction potential due to reallocation and resource-sharing of shipping containers multiple times within its life span. Such studies can help in understanding how circular practices and collaborative consumption can reduce the Scope 3- based emissions during mega event.

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Declaration of Competing Interest

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